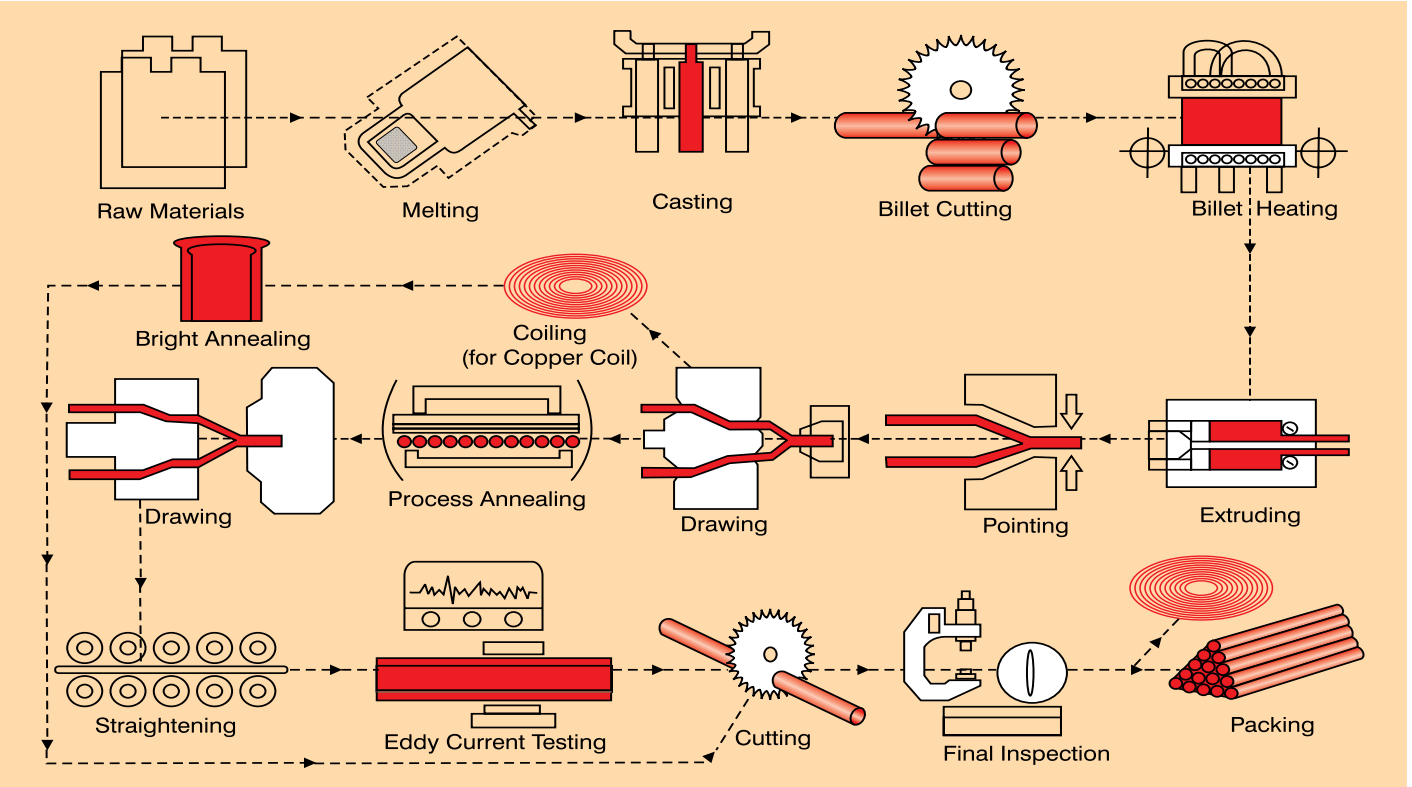

Copper Tube Manufacturing – Process Flow Chart

Copper Tubing for AC&R – its Manufacture & Application

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From the mines of Chile in South America, the largest producer of the copper ore in the world, to the copper tube manufacturers in India, is a long journey. AC&R grade tubing, in particular, must be carefully processed so that it is oil-free, dust-free and moisture-free in order to prevent contaminating the refrigerant circulating through the tubing. Proper application of such tubing in the field is equally important.

Production of Copper - an Overview

Copper ore is found throughout the world but the low percentage of metal content obtained from the ore and the often hard-to-access location of deposits make many potential mines uneconomic. Chile in South America is the world's largest producer of copper, which plays a major role in the country's economy. Zambia and the Congo Republic in Africa are also large producers. USA too has many copper mines, including the first open-pit copper mine in the world. India has small deposits in Rajasthan, Jharkhand and Madhya Pradesh.

An open-pit copper mine in USA

Copper ores often contain very low concentrations of the metal. Because of this, many stages of production process focus on eliminating impurities. The ore is first crushed and milled before entering a flotation chamber, in which copper will concentrate at the top while unwanted

About the Authors

Ramesh Munot takes keen interest in creating awareness in the Industry about the importance of quality in copper tubing used by the AC&R industry.

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fragments will sink. Next, the concentrate, enters a furnace where more impurities are removed. After the smelting process in the furnace, and the removal of waste gases the molten pool of copper is 60 – 65%. It is called Matte, which settles at the bottom of the furnace, while on the top is slag, which is drained off. The Matte is put into converter to get 98 % Copper called Blister. This is put in Anode Furnace for fire refining to get Cast Anode. This Cast Anode gets refined in Electrolytic cell to achieve 99.99 % pure Copper cathode before it is ready to be used for the manufacture of products such as tubing and electric wires.

Manufacturing of Copper Tubing in India

Generally, copper tubing manufactured in India, starts with raw virgin copper in the form of Cathode, melted and cast into solid Billets and then hot extruded in the form of hollow sections called Mother tubes or Shells, in sizes ranging from 38 mm to 150 mm OD, in lengths of approximately 6 metres. Scrap copper is also used as raw material to produce the mother tubes but because of unknown impurities that may be present in the scrap, such mother tubes should never be used to produce tubing for AC&R applications.

The mother tube (shell) is mechanically pulled in a Cold Drawing process, between a die and mandrel, with a gradual reduction in the inner and outer diameter of the tube. This process of several cold drawings, which is repeated between 5 to 15 times, results in achieving the required outside diameter and wall thickness of the finished tubing with specified tolerances. The Cold Drawing process requires a lubricant to form a thin continuous film between the tube and the tools, so that there is no direct solid-to-solid contact during drawing, thus minimizing heat generated, higher drawing speeds, enhancing tool/die life and better surface finish. The use of a **special (total loss)** lubricant that evaporates without any residue after the drawing process, helps to produce **'clean'** tubes with **low residue**, below the permissible levels of **0.038 gm/sq.m.** conforming to ASTM B:280 specifications.

Cold Drawing of the tubing is followed by Bright Annealing, which is a process of heat treatment that renders the metal soft, minimizes internal defects in the atomic structure of the material and relieves it from internal stresses that might otherwise be present, because of the cold drawing process. Copper tubing for AC&R grade is best annealed by heating and rapid cooling in a vacuum (oxygen-free atmosphere) of the order of 10^{-3} mm. Vacuum batch annealing also facilitates removal of vaporized invisible oxide film on the tubes that acts as a protective film during storage, besides retaining a 'bright' look. The surface finish of vacuum annealed copper tubes is excellent and additional processing cost is reduced.

Multiple Uses of Copper Tubing

Copper tubing has many different uses all over the world. For plumbing applications, it is very commonly used in many foreign countries for conveying hot and cold water in bathrooms and kitchens. It is also used for compressed air, natural gas, liquefied petroleum (LP) gas, medical gases in hospitals and vacuum lines.

Molten copper being drained out from a smelter

It is also very commonly used in air conditioning and refrigeration systems, all over the world, without exception, and is known as **Air Conditioning and Refrigeration (AC&R) tubing.** Such tubing must be especially processed to give the desired characteristics.

The following points differentiate AC&R Grade copper tubes from the regular copper tubes:

1 These tubes must have a clean tube surface with **low residual content** below the permissible levels of 0.038 g/m^2 for compatibility with use of CFC-free refrigerants, like R134A and R410A. For maintaining cleanliness, tube ends are sealed with plastic end caps for identification, traceability and authenticity of a genuine product and the tubes are then sealed in polythene bags to protect them from any tarnishing that may occur due to exposure to oxygen in the atmosphere.

2 Close control on chemical composition using **DHP** grade copper tubes with **RoHS compliance**. **DHP** Grade refers to *"De-oxidised High Residual Phosphorus"* Grade copper which conforms to ASTM B:68 standards with UNS Code of C12200 specifications of 99.9% copper and 0.015 to 0.040% Phosphorus content. **RoHS** refers to *"Restriction of Hazardous Substances"*, which have been listed as banned substances under the European Union (EU) compliance. The levels for *Reduction of Hazardous Substances (RoHS)*, like Lead, Mercury, Chromium, Bromine and its compounds should be below 1000 ppm and Cadmium below 100 ppm.

3 These tubes are produced with a dimensional tolerance conforming to ASTM B:251 which ensures perfect outer diameter and wall thickness within strict tolerances that ensures a perfectly smooth inner tube surface without **ovality**.

4 These tubes are 100% **Eddy Current tested** to ensure they are leak-free and valuable refrigerant filled in the tubes does not escape. Eddy current testing conforms to ASTM E:243, for supply of 100% flawless copper tubes.

5 These tubes are consistent along the entire tube length as far as hardness and tensile strength are concerned, helping in the durability and trouble-free functioning of the piping installation.

Working with AC&R Tubing

The correct size, layout and installation of ACR tubing, piping

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and fittings helps to keep a refrigeration or air conditioning system operating properly and prevents refrigerant loss. The piping system provides a passage for the refrigerant to the evaporator, the compressor, the condenser and the expansion valve. It also provides the way for oil to drain back to the compressor. To make the best use of this tubing, make sure you learn how to handle it and work with it while installing or repairing it in the refrigeration system.

Types and Sizes of AC&R Tubing

Copper tubing is available in soft or hard-drawn condition. Soft tubes may be bent or used without elbows. Hard-drawn tubing is not intended to be bent; use it only with fittings to obtain the necessary configuration.

AC&R tubing is sized by its Outside Diameter (OD); for example, half-inch tubing has an OD of half inch.

Table 1: Copper tube sizes used in AC&R applications

Actual Copper Tube Size					
OUTSIDE DIAMETER			WALL THICKNESS		
MM	INCH (FRACTION)	INCH (DECIMAL)	MM	INCH	GAUGE (SWG)
6.35	1/4	0.250	0.81	0.032	21
9.52	3/8	0.375	0.81	0.032	21
12.70	1/2	0.500	0.81	0.032	21
15.88	5/8	0.625	0.99	0.039	19
19.05	3/4	0.750	0.81	0.032	21
22.23	7/8	0.875	0.81	0.032	21
25.40	1	1.000	0.88	0.035	20
28.58	1 1/8	1.125	0.99	0.039	19
31.75	1 1/4	1.250	1.10	0.043	18½
34.93	1 3/8	1.375	1.20	0.047	18
38.10	1 1/2	1.500	1.30	0.051	17½
41.28	1 5/8	1.625	1.43	0.056	17

Soft copper tubing is normally available in 50-ft. coils and in diameters from ¼" to 7/8". Table 1 shows common tube diameters and thickness. AC&R tubing is cleaned, dried, and capped to prevent contamination by moisture and other foreign particles in accordance with **ASTM B:280** standards. When a piece of tubing is not used, the ends should be sealed to keep it clean and dry for later use in refrigeration systems. In addition to cleaning and dehydrating, in hard-drawn tubing reusable plugs are inserted in the ends.

ACR tubing is capped on each end to keep it dry and clean inside and often has a charge of nitrogen to prevent ingress of air and keep it free of any contamination or tarnishing the inside wall of the tube. Proper practice should be used to remove tubing from the coil. Never uncoil the tubing from the side of the roll. Place it on a flat surface and unroll it, cut only what you need and recap the ends.

Do not bend or straighten the tubing more than necessary because it will harden. This is called work hardening. Work-hardened tubing can be softened by heating and allowing it to cool slowly. This is called annealing. When annealing, don't use a high concentrated heat in one area, but use a flared flame over one foot at a time. Heat to a cherry red and allow to cool slowly.

Hard-drawn copper tubing is available in straight lengths of up to 20 feet and in larger diameters than soft copper tubing. Be as careful with hard-drawn copper as with soft copper, and recap the ends when the tubing is not used.

Cutting Tubing

To cut tubing, use either a hacksaw or a tube cutter. The tube cutter is usually used on smaller, annealed (soft) copper tubing. The hacksaw is preferred for cutting larger, hard copper tubing. The tubing should be straight and cut squarely (90°) to eliminate an off-center flare. The cutter usually leaves some sharp burrs on the cut ends. Burr must be removed by reaming (scraping with a pointer tool). Most tube cutters have a reamer.

Figure 1: A tube cutter

It is important that no filings or chips of any kind enter the tubing. When cutting tubing with a hacksaw, do not allow the chips to fall into the section that is to be used.

If soft tubing is used, pinch the end of the tube on the unused side of the cut. This eliminates the danger of chips entering the tubing. It also seals the tubing against moisture and protects it until used. In hard copper tubing installation, cap or plug the ends of the unused section.

Bending Tubing

It takes practice to become good at bending tubing. Special bending tools are not needed for smaller sizes used in domestic appliances. However, a much neater and more satisfactory job is possible with such tools.

Tubing should be bent so that it does not place any strain on the fittings after it is installed. Be very careful when bending the

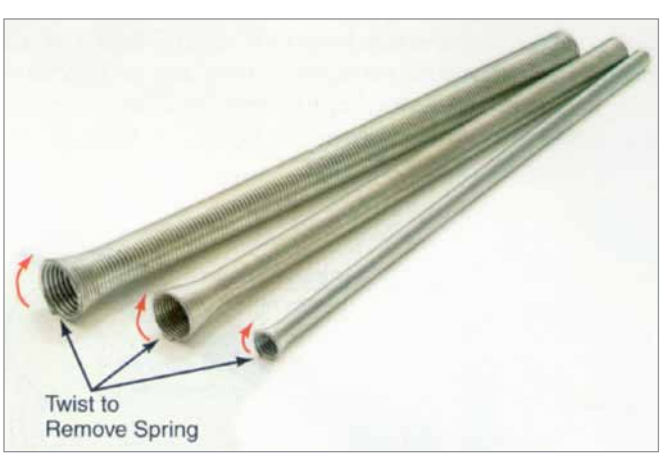

Figure 2: Three spring benders used for 1/4" through 3/4" tubing

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tubing to keep it round. Do not allow the tubing to kink, flatten, or buckle. The minimum radius for a tubing bend is between 5 and 10 times the diameter of the tubing.

Tubes should be bent quite slowly and carefully. It is always wise to use as large a radius as possible. This reduces the amount of flattening. It is also easier to bend a large radius. Do not try to make the complete bend in one operation; rather, bend the tubing gradually. There is less danger that the sudden stress will break or buckle the tubing.

An inexpensive tool called a bending spring may be easily carried in a tool kit. These are available in a variety of sizes and can be used outside the tubing to be bent.

Bending springs tend to bind on the tubing after the bend. They may be easily removed by twisting the spring. This changes the spring diameter slightly so the grip on the tubing is released.

If a bend is to be made near the flare and an external spring is to be used, bend the tubing before making the flare.

Expansion Tools

Figure 3: Expansion tool

They are used to enlarge one end of the piece of tubing so that two pieces of the same size (outside diameter) can be soldered together, eliminating the use of a coupling. Each size tubing requires a separate expansion tool. Expansion tools are used with the flaring block part of the flaring tool. The tubing is inserted into the proper-size die with enough length extending out to allow the expansion process to be completed with the block tightened securely. Do not extend the tubing too much past the block because the tubing may bend and ruin the expansion. If, however, too little tubing is extended, it may be cut when the expansion tool reaches the flaring block. After the tubing is properly placed in the block, the expansion tool is placed in the tube and struck with a hammer. Between each blow with the hammer, rotate the expansion tool to prevent its sticking to the tubing. Should it stick, a few light sideways flicks with the hammer will loosen the expansion tool and allow its removal from the tube.

Figure 4: Factory supplied expanded end tubing. Photo courtesy of Mandev Tubes

Figure 4 shows a factory made one-end expanded copper tube that saves the need for couplings in long length of piping joints, reduces the number of joints by 50%, reduces the cost of brazing by 50% and reduces the chances of potential leakage from joints also by 50%.

Tubing Reamers

Tubing reamers are used to remove burrs from refrigeration tubing. After the tubing has been cut, the reamer is placed over the tube and rotated, removing the burrs from either the inside or the outside of the tube. Then the reamer is turned around and placed over the tube again and rotated to remove the burrs. Since these are multisized tools, one tool will fit many sizes of tubing.

Pinch-Off Tools

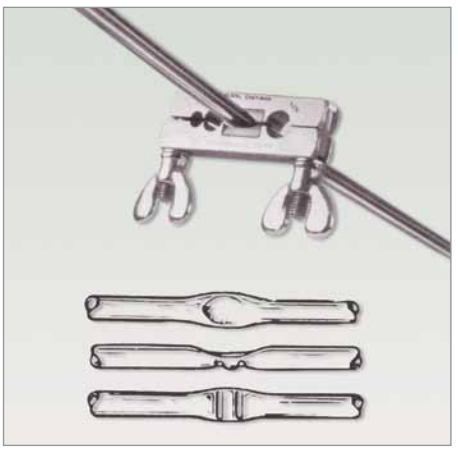

Figure 5: Pinch-Off tool and positive seals made

Pinch-off tools are used to block the escape of refrigerant from a sealed system through the process tube after service operations have been performed. After the service operations are finished, the pinch-off tool is placed on the process tube of the system and tightened. The tool closes on the tube and causes a positive seal. The service tools are then removed and the process tube is sealed with silver solder. The pinch-off tool is then removed.

Connecting Tubing

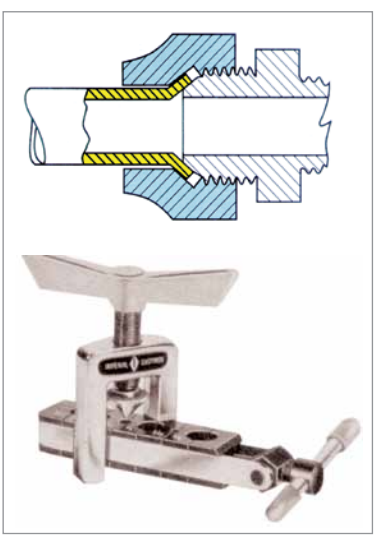

Figure 6: Flared connection and a flaring tool

Tubing walls are too thin for threading. Therefore, other methods of joining tubing and tubing to fittings must be used. The three common methods are :

- Flared connections.
- Soldered connections.
- Brazed connections.

Flared Connections

When connecting tubing to fittings, it is common practice to flare the end of the tube. Fittings designed to grip the tube are then used. Special tools are used for making flares.

A correctly formed flare is squeezed tightly between the flare nut and the coupling. A vapor-tight seal results.

Some flares are made from a single thickness of the tube. Other flares are made with a double thickness of metal in the flare surface. These double flares are stronger and usually cause few problems if properly made.

Most flares are made at a 45° angle to the tube.

Soldered or Brazed Tubing with Fittings

Most tube fitting connections are made by either soldering

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or brazing. Soldered joints are used for water pipes and drains. Brazed joints are used for refrigerant pipes and tubing. The terms "soft soldering" and "brazing" are often misused The difference between soldering and brazing is the lower temperature at which solder flows. If the temperature required to melt the alloy used to join copper tubing is below 840°F (450°C) , it is considered **soldering**. If the temperature required to flow the alloy is above 840°F (450°C), it is referred to as **brazing**.

Table 2: Safe working internal pressures [kPa] of AC&R tubing

Actual Copper Tube Size						Wt. per mtr.	Temper	Safe Working Pressure (Kpa)		
OUTSIDE DIAMETER			WALL THICKNESS					Service Temperature °C.		
MM	INCH (FRACTION)	INCH (DECIMAL)	MM	INCH	GAUGE (SWG)	kgs.		50	60	70
6.35	1/4	0.250	0.70	0.028	22	0.1111	Soft	9175	8550	7920
6.35	1/4	0.250	0.80	0.032	21	0.1247	Hard	10635	9910	9180
9.52	3/8	0.375	0.70	0.028	22	0.1735	Soft	5900	5495	5095
9.52	3/8	0.375	0.80	0.032	21	0.1960	Hard	6800	6335	5870
12.70	1/2	0.500	0.70	0.028	22	0.2360	Soft	4345	4050	3750
12.70	1/2	0.500	0.80	0.032	21	0.2675	Hard	4995	4655	4310
15.88	5/8	0.625	0.80	0.032	22	0.3389	Soft	3945	3675	3405
15.88	5/8	0.625	0.99	0.039	19	0.4141	Hard	4930	4590	4245
19.05	3/4	0.750	0.80	0.032	21	0.4102	Hard	3300	3055	2810
22.23	7/8	0.875	0.80	0.032	21	0.4816	Hard	2840	2625	2410
25.40	1	1.000	0.88	0.035	20	0.6062	Hard	2630	2445	2260
28.58	1 1/8	1.125	0.99	0.039	19	0.7674	Hard	2720	2555	2390
31.75	1 1/4	1.250	1.10	0.043	18½	0.9472	Hard	2635	2435	2235
34.93	1 3/8	1.375	1.20	0.047	18	1.2440	Hard	2600	2420	2245
38.10	1 1/2	1.500	1.30	0.051	17½	1.3440	Hard	2735	2565	2400
41.28	1 5/8	1.625	1.43	0.056	17	1.7283	Hard	2840	2690	2535

During soldering molten solder is drawn into the area between the fitting and the tube by capillary action. The selection of a solder is based upon two factors: operating pressure and temperature of the line. A tin-antimony solder is appropriate for moderate pressures and temperatures. It melts at 360°F (182°C) and is fluid at 415°F (213°C). For higher pressures or greater joint strength, a 95/5 tin-antimony solder is used. The mixture contains 95% tin and 5% antimony. A 95/5 solder melts at 450°F (232°C) and is fully liquid at 465°F (241°C).

Brazing produces a stronger bond than soldering. Brazing filler metals can join similar and dissimilar metals at brazing temperature. Brazing filler metals melt at temperatures in the range of 1000°F to 1500°F (538°C to 816°C). Strength of a brazed copper joint depends more upon proper clearance between the tube and the socket of the fitting.

All air must be removed from the tubing being brazed. This can be best done by purging the tubing with either carbon dioxide or nitrogen. Any oil inside the tubing or part may be vaporized by he heat of the torch. Oil vapor mixed with air will explode if ignited. Using a nonflammable gas such as carbon dioxide or nitrogen will eliminate this hazard.

Caution : Never use a refrigerant, oxygen, or compressed air when brazing.

Pressure Testing & Safe Working Pressure

After completing the installation of the entire refrigerant piping system in an AC&R plant, the system must be pressure tested to ensure that all joints are leak-free, before drawing a vacuum in the system and charging refrigerant. After ascertaining from the system manufacturer, the refrigerant used and its working or operating pressures, the "TEST" pressure is determined by multiplying the maximum working pressure by 1.5.

Safe Working Pressures

Safe working pressures of copper tubing shown in *Table 2* will vary with the size of tubing and the temperature of the material inside the tube. When the temperature of the material (refrigerant in this case) increases, the safe working pressure of the tube decreases.

Changing Tube Sizes

Many times an installation and service technician will be required to change sizes of refrigerant piping. The proper way to accomplish this is to use a reducing fitting. However, many times he will not have all the necessary fittings. This problem can be overcome very easily in most cases, especially when changing the size of tubing. The tubing used in refrigeration work is sized in 1/8 in. (3.175mm) increments. This allows one size of tube to be placed inside the next larger size of tube. A joint made this way is to be soft soldered. However, silver solder will work very satisfactorily. This type of joint is commonly used in service and installation procedures.

Line Repair

Line repair is sometimes needed when a cracked line occurs and the desired fittings are not available. The service technician may repair the line satisfactorily by using silver solder to repair the crack and get the system operating again. First, be certain that no pressure exists in the system because injury may result if the pressure builds enough to blow hot oil and metal from the line. Next, clean the joint with sand cloth and apply silver solder flux. **Note: This procedure should not be attempted with soft solder**.

Heat the line to a dull cherry red and apply silver solder until the area around the crack is slightly built up. Be sure not to overheat the tube. This type of repair will last indefinitely if properly done.

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Equivalent Length of Pipe

The use of equivalent length of pipe is very important in refrigerant piping procedures. The number of fittings in a refrigeration system should be kept to a minimum. Every turn encountered by the refrigerant flowing through the tubing is an added point of resistance. Excessive resistance will reduce the equipment capacity. Every elbow gives an added resistance (pressure drop) equal to a given length of that size tubing (*Table 3*). Pressure drop and line sizing tables are usually designed on the basis of a given pressure drop for each 100 ft (30.4 m) of straight pipe. Therefore, the use of an equivalent length of pipe allows the data to be used directly.

When accurate calculations of pressure drop are required, the equivalent length for each fitting should be calculated. In practice, an experienced system designer may be capable of making an accurate overall percentage allowance unless the piping arrangement is very complicated. For long runs of piping (100 ft or more) a 20 to 30% allowance of the actual length may be adequate. For short runs an allowance as high as 50 to 75% of the lineal length may be required. Judgment and experience are necessary in making a good estimate. These estimates should occasionally be checked with actual calculations to ensure reasonable accuracy.

Table 3: *Equivalent length [ft] of straight pipe for valves and fittings*

OD Line Size [in.]	Globe Valve	Angle Valve	90 Elbow	45 Elbow	Tee Line	Tee Branch
1/2	9	5	0.9	0.4	0.6	2.0
5/8	12	6	1.0	0.5	0.8	2.5
7/8	15	8	1.5	0.7	1.0	3.5
1 1/8	22	12	1.8	0.9	1.5	4.5
1 3/8	28	15	2.4	1.2	1.8	6.0
1 5/8	35	17	2.8	1.4	2.0	7.0
2 1/8	45	22	3.9	1.8	3.0	10.0
2 5/8	51	26	4.6	2.2	3.5	12.0
3 1/8	65	34	5.5	2.7	4.5	15.0
3 5/8	80	40	6.5	3.0	5.0	17.0

Conclusion

This article can be considered as a primer on AC&R copper tubing, its qualities, advantages and application. With the help of proper tools and some practise in the use of such tools in the workshop, any technician can soon become an expert in handling and installing trouble-free refrigeration systems.

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